

**STATEMENT
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**BEFORE THE
ENERGY AND NATURAL RESOURCES COMMITTEE
UNITED STATES SENATE
December 10, 2009**

Thank you, Chairman Bingaman and members of the Committee, for this opportunity to testify before you on grid-scale energy storage and its role in achieving U.S. energy and climate goals.

Enhancing our national energy storage capability is an important tool to improve electric grid reliability and resiliency. Adequate deployment of storage technologies can materially reduce power fluctuations, enhance system flexibility, and enable greater integration of variable generation renewable energy resources such as wind and solar power. Each of these is critical for achieving the Nation's clean energy goals. Energy storage can also help stabilize the price spikes that occur during times of peak demand, and can delay or potentially avoid the need to construct capital intensive facilities and infrastructure that use conventional fuels and produce greenhouse gases.

The core function of energy storage is to bridge the gap that exists between the characteristics of the generation and load technologies within our electrical system. While some have identified this gap as a challenge inherent only to variable generation renewable energy technologies such as wind and solar, gaps and mismatches in characteristics exist throughout the grid that stress our infrastructure; these areas would benefit from the system flexibility that could be introduced with deployment of grid scale energy storage technologies. Power quality disturbances resulting from voltage and frequency fluctuation are but one indication of the stresses that exist in today's grid that could be ameliorated by increased energy storage. However, the functional requirements of energy storage for power conditioning are necessarily different than the functional requirements of energy storage for load shifting or variable generation firming, and it is therefore no surprise that different applications require different storage technologies.

It is important to recognize that despite the large number of existing energy storage technologies, there are only a limited number of known fundamental phenomena that can be exploited to store energy; currently these phenomena include gravity, electron movement and storage, mechanical conversion, chemical manipulation of materials, and thermal storage. The conversion process between energy states that enables storage also defines the characteristics of each storage technology, as well as the applications for which the technology is best suited. Gravity storage via pumped water, where each acre foot of water pumped contains more than 1 kilowatt-hour of potential energy for each foot of elevation increase¹, has the potential to store great amounts of

¹ Potential energy is calculated to the theoretical limit and does not include efficiency losses from conversion between energy states. The theoretical potential energy for an acre foot of water is 1.02 kilowatt-hours per foot of

energy and is well suited for large energy applications such as load leveling. Yet the requirement that water be moved limits the short time response capability of the technology. Conversely, mechanical kinetic energy storage via flywheels is particularly well suited to the short term requirements of power conditioning; and while flywheel systems can achieve very high energy densities², the physical constraints on flywheel size limit energy storage for extended activities such as peak shifting. Given the variety of conversion processes involved, it is critical that energy storage technologies be matched to potential applications.

The power requirements for energy storage range from of a few watts for personal electronics, up to 100 kilowatts for hybrid vehicles, tens of megawatts for ships, and hundreds of megawatts for electric utility applications. The duration requirements for these same applications covers a similarly broad range, from sub-second for power quality and voltage regulation to hours or even a day when peak shaving and load leveling. Among the most important requirements for stationary utility storage, which ranges from half a megawatt to hundreds of megawatts, are storage technologies that are low-cost and have a high cycle life, meaning a large number of charge and discharge cycles. High reliability, efficiency, environmental acceptability, and safety are also important. Unlike requirements for electric vehicles where energy density for conventional fuels is held as the benchmark against which storage technologies are compared, energy density and footprint are less important for utility storage.

Grid-scale energy storage received a significant boost through the American Recovery and Reinvestment Act. On Nov. 24, 2009, the Department announced it would award grants totaling \$185 million to 16 energy storage demonstration projects³. This investment will substantially accelerate the development and deployment of utility-scale storage technologies, enhancing their market readiness in the U.S.

The Department of Energy's Office of Electricity Delivery and Energy Reliability has the lead within the Department for energy storage research, development, analysis, and demonstrations associated with the electric grid. The program works with numerous utilities to ensure that projects reflect the industry's needs, and close collaboration with the states has resulted in many jointly funded demonstration projects. In addition, the Office of Science selected six Energy Frontier Research Centers in the area of energy storage⁴ to perform fundamental research relevant to battery technology. The Advanced Research Projects Agency-Energy (ARPA-E) has also selected six energy storage projects⁵ as part of its first solicitation for breakthrough technologies.

elevation increase.

² Castelveccchi, D. (2007). Spinning into control. *Science News*, vol. 171, pp. 312-313

³ Project list available at http://www.energy.gov/news2009/documents2009/SG_Demo_Project_List_11.24.09.pdf

⁴ Center for Electrical Energy Storage

Center for Electrocatalysis, Transport Phenomena and Materials for Innovative Energy Storage

Energy Materials Center at Cornell

Northeastern Chemical Energy Storage Center

Center for Science of Precision Multifunctional Nanostructures for Electrical Energy Storage

Heterogeneous Functional Materials Center

⁵ High-Amperage Energy Storage Device-Energy Storage for the Neighborhood

Planar Na-beta Batteries for Renewable Integration and Grid Applications

Low Cost, High Energy and Power Density, Nanotube-Enhanced Ultracapacitors

Metal-Air Ionic Liquid (MAIL) Batteries

In fact, one project in the first ARPA-E tranche that has captured people's imagination is a storage technology, the liquid metal battery, so it is possible that storage is an area where truly creative thinking is possible.

Grid Reliability and Frequency Regulation

Reliability and power quality have become a necessity for the modern digital society because digital equipment is extremely vulnerable to short outages and even small voltage fluctuations. Studies have shown that momentary outages, lasting less than 5 minutes, cost the U.S. some \$52 billion annually⁶. Energy storage with high frequency characteristics and response rate enables seamless continuity of power supply for a range of customers. One system of valve regulated lead-acid batteries, that was developed with Department of Energy funding, can protect energy intensive and highly sensitive facilities like microchip plants with 10 megawatts or more for 30 seconds, after which a back-up diesel generator can provide the necessary power. Similar systems are widely used for high tech manufacturing, financial institutions, and server farms. On a larger scale, a single 27 megawatt nickel cadmium battery safeguards the transmission line from Anchorage to Fairbanks by giving voltage support, preventing outages, and providing reactive power locally.

The need for frequency regulation arises because generation and demand are almost always out of synch. The resultant grid system is one which regional operators are required to balance by adjusting the frequency. Current management involves sending periodic signals that allow participating fossil fuel generators to increase or decrease production and reset the frequency. Fast storage performs this function considerably better. Studies have shown that regulating frequency by battery or flywheel storage is at least twice as effective and has a 70 percent reduced carbon footprint compared to use of fossil fuel generation⁷. Technical feasibility was shown by flywheel demonstrations funded by the Department jointly with state agencies in California and New York. Currently there are six 1 megawatt demonstration units operating on the grid, and through the Loan Guarantee Program the Department has entered into a conditional commitment for the development and deployment of a twenty megawatt flywheel energy storage facility in New York⁸. Meanwhile, under the guidance of the Federal Energy Regulatory Commission grid operators are developing new control signals, tariffs, and market rules to allow frequency regulation by fast storage to be deployed in a cost effective manner. With increased deployment of variable generation renewable energy assets, the need for frequency regulation on the grid will increase considerably.

Silicone Coated Nanofiber Paper as a Lithium-Ion Anode
High Energy Density Lithium Batteries

⁶ Hamachi-LaCommare, Eto. *Understanding the Cost of Power Interruptions to U.S. Electricity Customers*. Lawrence Berkeley National Laboratory (2004)

⁷ Makarov, Ma, Lu, and Nguyen. *PNNL Report #17632: Assessing the Value of Regulation Resources Based on Their Time Response Characteristics*, Pacific Northwest National Laboratory (June 2008)

Fioravanti and Enslin. *KEMA Report #BPCC.0003.001: Emissions Comparison for a 20MW Flywheel-based Frequency Regulation Plant* (2007)

⁸ \$43 million conditional commitment for a loan guarantee to Beacon Power
(<http://www.lgprogram.energy.gov/press/070209.pdf>)

Asset Utilization and Renewable Integration

It is well known that generation, transmission, and distribution are not efficiently utilized. Assets such as substations and transmission lines have to be sized for peak demand with ample capacity to spare for a hot day. One quarter of a facility's capacity is devoted to maintaining service during a 5 percent peak period. The goal of energy storage is to supply this peak load from energy stored during periods of least demand, thereby allowing for more complete and cost effective utilization of grid assets.

In particular, substation load can easily outgrow the original unit target size. Instead of an immediate and costly upgrade, installation of energy storage can be more economical and flexible, and is therefore finding favor with utilities. The first application in the U.S. was sponsored by the Department of Energy and American Electric Power in 2006 at a substation in West Virginia. The substation had been reaching its capacity limit and an upgrade was needed quickly to handle the overload during peak periods. Instead, energy storage was installed, so that energy is stored at night when the substation is not stressed and electricity is less expensive, and then released over a 6-hour period during peak load times. The system, using a sodium sulfur battery, has performed well and installation of storage will defer substation upgrades by 5 to 6 years. Seven more megawatts have since been deployed in similar installations at several utilities. Other utilities are planning to test flow batteries or lead-carbon batteries in efforts to defer substation upgrades.

While energy storage is important for reliability and efficiency of the grid, it is expected to become increasingly important for complementing and buffering increasing amounts of variable generation. Variability of wind and solar generation comes in three different time scales. Short term fluctuations of seconds or minutes are similar to the fluctuations created by load variability, and these fluctuations can be handled effectively by fast storage facilities placed on the grid for frequency regulation. Ramping over the course of hours – as sometimes occurs with wind generation - is an important issue for utilities, and energy storage can be used to address this challenge. With energy storage equivalent to a one hour reserve, the number of gas turbines required for ramp control could be reduced, thereby improving the economics of wind energy generation.

Another challenge results from the wind patterns that occur in areas where strong nighttime winds are common. Because night load is small when compared to daytime load, in such a scenario renewable resources can have a larger share of the generation mix during the night than during the day, resulting in periods when the value of continued generation of wind energy is challenged. In West Texas, for example, over nine hundred 15 minute intervals of negative pricing occurred during one month in 2008, and a number of wind developers in the area are beginning to realize that energy storage might lead to economic advantages and better utilization of wind energy.

Although interest is increasing, the United States has only a few megawatt-sized demonstrations of storage for the integration of renewable resources. In Japan, by contrast, a 34 megawatt/7 hour sodium-sulfur storage facility has been constructed in conjunction with a 51 megawatt wind farm.

All excess night time generation is absorbed by the battery, resulting in completely dispatchable wind power during the day. While Japan encourages construction of energy storage associated directly with wind development, storage in the United States is viewed as a grid requirement which might be placed anywhere within a region. One hundred megawatt battery farms have been proposed domestically, but none has yet been constructed. An alternative approach which has been suggested is the introduction of community energy storage. Relatively small storage units of some 25 kilowatts would serve a cluster of 4-to-5 residences to provide emergency backup or to serve as a platform for installed photovoltaics. Individual units would also be aggregated into a centrally dispatchable fleet. This would provide the utility with a sizable resource for ramping, spinning or stand-by reserve, or other ancillary services.

For yet larger amounts of energy, compressed air energy storage (CAES) can be used. For this technology, air is compressed off peak and stored in salt domes, man made caverns, or deep aquifers. When extra energy is required during peak periods, air is released and fed directly into natural gas combustion turbines, eliminating the need for a compressor. While the current technology does not eliminate the need for fuel, it increases the efficiency of the turbines substantially, thereby reducing the carbon intensity of the generated electricity. There is also ongoing research into the use of adiabatic CAES technology, which does not require combustion of fossil fuels as the stored energy is converted back into electricity⁹. There are two CAES units in existence – one in Germany (290 megawatts) and one in Alabama (110 megawatts), and both facilities use salt domes formed by solution mining. CAES units could be used to take advantage of day-night power pricing arbitrage or as spinning reserve. Most proposed new plants intend to charge entirely with available wind energy, resulting in a very favorable carbon footprint. Besides producing electricity during peak periods, the plants can also provide system flexibility by absorbing excess energy whenever a wind increase occurs. This would eliminate the need for fossil fuel standby peaking plants.

Currently the best form of energy storage to handle really large quantities of energy is pumped hydro. Using reversible turbines, water is pumped into an upper reservoir during periods of inexpensive night power and released during periods of peak load to generate electricity. Some 20 gigawatts of pumped storage hydro plants are in use by utilities in the United States, which amounts to about 2.5 percent of the total U.S. electrical capacity. Europe has about 32 gigawatts of pumped hydro, or 10 percent of capacity, and Japan has as much as 15 percent which results in a very resilient grid capable of absorbing substantial amounts of renewable energy¹⁰.

An impressive 440 megawatt pumped storage hydro plant in Missouri is scheduled for completion in 2010, and an additional 15 gigawatts of pumped hydro are either planned or in the permitting stage in the United States. Further new construction is hampered, however, by environmental concerns, the current price of cement and steel, and a very lengthy permitting process extending over many years.

⁹ Bullough, Gatzert, Jakiel, Koller, Nowi, and Zunft. *Advanced Adiabatic Compressed Air Energy Storage for the Integration of Wind Energy*. EWEC 2004, London UK.

¹⁰ 22% of generation capacity in Japan was attributed to renewable energy technologies during 2007, including hydropower (source: *World Energy Outlook 2009*, IEA)

Grid-Scale Energy Storage Demonstrations under the American Recovery and Reinvestment Act

The American Recovery and Reinvestment Act of 2009 provided unprecedented opportunity to accelerate the deployment of grid scale energy storage. On November 24, 2009, Secretary Chu announced the selection of 16 energy storage demonstration projects in conjunction with selection of Smart Grid demonstration projects¹¹. The selected energy storage projects ranged over the entire spectrum of grid applications and will enhance grid reliability and efficiency, enable community energy storage options, and allow for greater use of renewable energy resources. Technologies include advanced batteries, flywheels, and compressed air energy storage. The selected awards total \$185 million in Recovery Act funding but represent a total project value of \$770 million based on substantial recipient cost sharing of between 50 to 80 percent of total project cost. The awards fall into five areas:

- Peak Reduction and Wind Farm Integration— three projects were selected with a federal cost of \$61 million. The selected projects are intended to demonstrate the potential for battery storage to improve asset utilization, allowing better use of night time wind energy and grid integration of intermittent resources, thus increasing their share of the generation mix. These demonstrations in California and Texas will fund battery facilities in the 8 to 25 megawatt scale, a magnitude larger than current installations.
- Frequency Regulation Services for Stabilization of the Power Load – one project was selected for an award of \$24 million. Electricity generation and load are never exactly synchronized. To balance them, regional system operators slightly shift the load frequency, by either increasing or decreasing power production. Using fast storage devices for these adjustments is twice as effective as using fossil fuel plants. A 20 megawatt flywheel system to be located in Illinois is ten times larger than existing demonstration units.
- Distributed Energy/Community Storage – five projects were selected totaling \$20 million, which will allow utilities to experiment with smaller scale storage. Distributed energy storage strengthens and buffers the grid and allows utilities to deal effectively with load fluctuations or renewable generation. Utilities can use storage to provide peaking power during periods of high demand. The selected projects include a 3 megawatt installation in Pennsylvania to provide up to four hours of peak shaving, backup storage for a photovoltaic system in New Mexico, and aggregation of smaller systems into a community energy storage effort in Michigan.
- Compressed Air Energy Storage (CAES) – two projects for grants totaling \$54 million have been selected. A 150 megawatt CAES facility will be constructed in New York State using an existing salt cavern. The plant will have sufficient storage to allow full operation in support of the transmission system and market needs and support some 3,800 megawatts of wind planned in the area. A second CAES project will be sited in California. The 300 megawatt plant, using a saline porous rock formation, is situated next

¹¹ Project list available at http://www.energy.gov/news2009/documents2009/SG_Demo_Project_List_11.24.09.pdf

to a transmission line receiving power from an expected 4,000 megawatts of new wind. Together, the two new plants will double the world's CAES capacity and provide invaluable experience for developing a fleet of such plants throughout the U.S.

- Promising, emerging technologies – five projects were selected for grants totaling \$25 million. These new storage technologies are in their initial stage of development. Funding is intended to bring them to the prototype stage and ready for the market place. Among the projects are a Lithium-Ion battery with nanostructured polymer electrolyte, an iron-chromium based flow battery, and an isothermal compressed air technology that needs no extra fuel.

Successful implementation of these Recovery Act projects will depend not only on the diligence of the utilities and entrepreneurs involved, but also on the readiness of public utility commissions and regional system operators to accept the new technologies. As the new projects develop, they will be carefully monitored and fully integrated into the existing energy storage program at the Department of Energy. Results will provide a basis for analytical studies and economic modeling on the role of storage in a more sustainable electric grid.

Barriers to Deployment

Technological barriers to improved energy storage systems range from gaps in fundamental knowledge to operational limitations in current technology. The Department of Energy's Office of Science has the lead for fundamental research to develop new concepts and approaches for energy storage necessary to meet the long-term needs of our nation. Significant advances in our understanding of basic physical and chemical properties of electrical energy storage are needed, and recent developments in nanoscience are opening promising scientific avenues that require further exploration. Fundamental research provides continually developing insights which enable the pursuit of new energy storage technologies to address the operational weaknesses of today's technologies, including: rate of system charge and discharge, safety hazards from over-charging or discharging, environmental hazards from toxic materials, and short lifetimes.

Widespread deployment of energy storage systems is impeded by the lack of uniform standards identifying operational parameters across applications. These and other issues, including additional regulatory and market barriers, have been identified previously¹².

The final barrier to deployment is economics. Current costs are too high to allow reasonable rates of return for investors in most applications, which can range from \$1500/kW to \$4500/kW depending on the technology. Although systems are beginning to enter the market at \$2200-\$2500/kW for high value applications, additional cost reduction is necessary to increase penetration; cost targets are application specific. Some cost reduction will be achieved through economies of scale as production numbers increase, but much will have to come from improved systems. Novel materials and components for energy storage applications, from batteries to

¹² Electric Advisory Committee report - Bottling Electricity: Storage as a Strategic Tool for Managing Variability and Capacity Concerns in the Modern Grid - December 2008. (http://www.oe.energy.gov/DocumentsandMedia/final-energy-storage_12-16-08.pdf)

flywheels, must be developed to enable long system lifetimes while using low cost base materials and inexpensive manufacturing processes.

Conclusions

Energy storage offers a diverse portfolio of technologies for a wide spectrum of applications. It allows us to optimize operation of the grid to make the most of our resources. Energy storage can:

- Provide power quality and reliability;
- Provide voltage and frequency regulation;
- Smooth integration of variable generation renewable energy technologies into the grid;
- Allow better asset utilization for generation and transmission;
- Provide relief to customers and utilities during peak load periods; and
- Provide spinning reserve and energy management to make renewable energy technologies more dispatchable.

Our basic research is leading fundamental scientific advances needed for leadership in developing the next generation energy storage technologies, and advances in energy storage are an international interest. Besides the U.S., the European Union, Canada, Australia, and Japan have sizable storage efforts. China recently initiated a substantial storage program focused on flow batteries.

Other emerging technologies have the potential of enhancing or augmenting storage. Smart grid concepts, for example, could link storage to demand response and enable aggregation of distributed storage. Plug-in hybrids and, perhaps eventually battery electric vehicles, add a whole new dimension by linking transportation to energy management. Utilities are increasingly becoming involved in energy storage, and states like California and New York continue to work with the Department in funding new projects. Recovery Act funding is supporting frequency regulation and wind integration projects on a commercial scale. The investment community is becoming interested in providing venture capital for companies developing new technologies and in funding ambitious large scale projects. Industry appears poised to move from single megawatt scale applications to utility grade projects in the hundreds of megawatts. The eventual goal is to make energy storage ubiquitous and thus to contribute to the development of a greener and more resilient grid.

This concludes my statement. Thank you for the opportunity to testify, and I look forward to answering any questions you and your colleagues may have.